MULTIFOCAL MULTIZONE DIFFRACTIVE OPHTHALMIC LENSES

The present invention relates to multifocal lenses for correcting vision and, more specifically relates to bifocal lenses having at least one diffractive zone which is added to the basic refractive power of the lens.

BACKGROUND OF THE INVENTION

Ophthalmic lenses which have two or more distinct focal lengths are known. Such lenses have been used in the post as contact lenses which are disposed upon the surface of the eye, or as intraocular lenses (IOL's) which are surgically implanted to replace the natural crystalline lens after its removal during, e.g., cataract surgery. Diffractive lenses are well known within the field of optics generally, however they have as yet found only limited application to intraocular or contact lens design. Thus, although numerous designs have been disclosed for multifocal optics for use in contact or intraocular lenses, few have been found to be in any way practical.

Lenses relying solely upon refraction have been disclosed. For example, Nielsen, et al. U.S. Pat. No. 4,636,211 discloses a bifocal intraocular lens which has achieved by refraction, the central zone adapted for near vision and surrounded by a coaxial far vision zone. The lenses disclosed have either a plano-convex or bi-convex shape. Achatz et al. U.S. Pat. No. 4,813,955 discloses a multifocal intraocular artificial ophthalmic lens divided into near range and far range zones disposed symmetrically about the lens axis which uses the refractive power of the lens material and its shape to achieve bi-focal vision.

Designs of contact lenses which rely only upon the refractive properties of the Fresnel lens are also known. For example, Cohen U.S. Pat. No. 4,162,122 discloses a zonal bifocal contact lens comprised of a concave spherical or a spherical posterior surface and a continuous anterior surface which is divided into concentric annular rings which are alternately inclined to the optical axis, corresponding to curvatures appropriate for the near and distant foci. The interfaces of the annular zones are continuous and do not create any steps or jumps on the anterior surface. Each zone consists of a refractive element only, the zones forming a smooth anterior surface.

Lenses utilizing the combined properties of Fresnel lenses and Fresnel zone plates and which rely on the diffractive effects thereof are also known. Cohen U.S. Pat. No. 4,210,391 discloses multifocal optical lenses which have their multifocal properties distributed throughout the lens. The lenses disclosed share the incident light between the focal points by using a zone plate and splitting the incident light into discrete "bundles" each directed to a particular focal point. The design utilizes elements of both a Fresnel lens and a Fresnel zone plate, relying on the fact that such optical elements are comprised of concentric rings or zones and thus provides lens designs having reduced diffractive and chromatic aberrations. Cohen U.S. Pat. No. 4,338,005 also discloses a multifocal phase plate lens design which has multifocal properties distributed throughout the lens. The lens disclosed is comprised of concentric zones, the diameters of which are derived from the focal length desired and wavelength of light being focused. The performance of the lens is not de-

graded by the superposition of blurred images at the focal points. Also, Cohen U.S. Pat. No. 4,340,283 discloses a multifocal zone plate construction suitable for use in optical systems with multifocal requirements. A phase shift multifocal zone plate provides multiple foci by adjusting the zone plate spacings such that the zone plate foci coincide with multifocal Fresnel lens foci. The adjustment is obtained by ion implantation in certain sections of the lens, whereby the refractive index of the lens is altered in that section.

Additionally, others have attempted to combine both refractive and diffractive powers to create multifocal lenses. Freeman U.S. Pat. No. 4,673,697 discloses multifocal contact lenses utilizing diffraction and refraction by adding diffractive power to the basic refractive power of the lens. The diffractive power is provided by a series of concentric zones defined by surface discontinuities or refractive index changes. In a bifocal application, diffractive power is provided in addition to the basic refractive power of the lens, while maintaining the basic curvature of the front and rear surfaces. The diffractive zones deviate all of the incident light in the manner of a phase zone plate (Fresnel zone plate). The Freeman U.S. Pat. No. 4,673,697 teaches that it is important to maintain the radius of curvature of the rear surface of the lens at a value which will maintain close conformance with the cornea. Freeman U.S. Pat. No. 4,642,112 discloses bifocal artificial eye lenses which utilize a transmission holograms to provide diffractive power on a wavelength or amplitude selective basis in a manner which is additive to the basic refractive power of the lens.

When a diffraction element is used to provide two separate focal lengths, the maximum theoretical efficiency results in about 40.5% of the incident light forming an image at each focal distance. Therefore, the overall total efficiency of the lens is about 81%. The remainder of the light (about 19%) is scattered into higher order diffraction patterns and thus degrades the images formed, rather than enhancing them. Therefore, it would be desireable to provide multifocal lenses which utilize both diffractive and refractive elements and which exhibit an overall total efficiency closer to an ideal 100%.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a highly efficient multifocal lens. Accordingly, the present invention provides increased efficiency multifocal lenses by using at least one diffractive zone located in a defined portion of the surface of a refractive lens. The lenses of a first embodiment of the present invention are thus divided into two areas, a first area of highly efficient diffractive power and a second area having essentially no diffractive power. Most preferably, the diffraction zones provide substantially 100% efficiency in the +1 diffractive order. The non-diffractive zones allow light to be transmitted without appreciable deviation due to diffraction. Most preferably, the zones are of about equal area, thereby causing about one-half of the incident light to focus at each of the two focal planes, resulting in an overall lens efficiency approaching 100%.

In another preferred embodiment, lenses are provided which have two different diffractive elements disposed substantially across the entire lens surface. The two diffractive patterns are different in that they have different diffractive powers. Since the diffractive pow-